Non-Asymptotic estimation for on-line systems: Finite-time algorithms and applications

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by Jean-Pierre Richard and Wilfrid Perruquetti

Finite-time estimation is a way to perform real-time control and achieve specified time performance. The Inria project-team Non-A is focusing on designing such "non-asymptotic" algorithms: there, mathematics (algebra, homogeneity) are combined with real-time applications (robotics, energy, environment)…

For engineers, a wide variety of information is not directly obtained through measurement. Some parameters (constants of an electrical actuator, time delay in communication, etc.) or internal variables (torques applied to a robot arm, posture and localization of a mobile, detection of impact of angles in biped walk, etc.) are unknown or are not measured. Similarly, more often than not, signals from sensors are distorted and tainted by measurement noises. To control such processes, and to extract information conveyed by the signals, one often has to *estimate* parameters or variables.

Estimation can concern *parameters (identification), states (observation), derivatives (differentiation), inputs (left inversion)* or *noisy data (filtering)*. It means a nearly infinite number of results have already been produced in this area, concerning either control or signal processing… However, unlike traditional methods, the majority of which pertain to asymptotic statistics, the particularity of Non-A is to develop algorithms which converge after a *finite-time.* This is summarized in the project's name: "Non-Asymptotic estimation for online systems".

The project-team Non-A is a joint action of Inria with Ecole Centrale de Lille, University of Lille 1 and CNRS (LAGIS UMR 8219). It also involves members from ENSEA Cergy, University of Reims and University of Lorraine. It is located at the Inria research center Lille North-Europe and gathers 23 people (Researchers, PhD students, Post-Doc, Engineers) coming from 13 countries. It has been created in January 2011 in the continuity of a previous project ALIEN (leaded by Michel Fliess). After having successfully undergone its evaluation in 2013, Non-A is being supported by Inria until the end of 2017.

Why do we develop finite-time algorithms? In most fields of application, the time response constraint is crucial. Using our algorithms, computations are performed in real-time (i.e. as the application is running). *Finite time convergence* can benefit both the engineer who has to fulfill design specifications prior to certification, and the control researcher looking for a mathematical proof of his 'separation principle'.

Application fields are plentiful and past results have concerned robotics, vehicle control, aeronautics, hydroelectric power plants, shape-memory or magnetic actuators, power electronics, secured communications, financial engineering, image/video processing… Today, the team mainly focusses on the networked control systems, including WSAN (Wireless Sensors and Actuators Networks), but other applications range from circadian rhythms to high precision machining. Our ''model-free control'' also attracts various industrial contracts and has given birth to AL.I.E.N. SAS, a company created in Nancy.

Two complementary alternatives for finite-time estimation are considered. The first one develops an algebraic framework for identification initiated in 2003 (Fliess, Sira-Ramirez, ESAIM COCV, 9, 151-168). Recent results concern the fast estimation of time-delay systems [1], of frequencies in noisy periodic signals [2], of modes and states in switched systems [1], of impulsive systems, as well as the differentiation of multivariate signals… The other one develops the concept of homogeneous nonlinear systems and observers: roughly speaking, homogeneity [3] allows for extending local results, on a sphere, to global ones, in the whole space. Very recently we generalized this concept to time delay systems. Homogeneity applies to control, input-to-state stability, finite-time observers… but also to *fixed-time* stabilization [3], where the convergence time is fixed independently of the system's initial conditions (as illustrated on Figure 1).

Rather than being oriented to a specific domain of application, Non-A is a *method-driven project* (namely, algebra and homogeneity for fast estimation and control). However, one must not forget that applicability remains a guideline in all our research. Furthering the above mentioned fields, in the long term we concentrate our engineering effort on the *Internet of Things*, and more particularly the self-deployment of WSAN. Various packages are being developed within the ROS environment, for robots cooperation: cooperative SLAM, path-planning and path-tracking, localization with a reduced number of landmarks, etc. In a more ad-hoc way, some works also have environmental interests: biology (rhythms of bivalve molluscs for pollution detection), meteorology (sunshine prediction for solar energy management), fluid mechanics (limit flow control for energy saving).

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References

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[2] R. Ushirobira, W. Perruquetti, M. Mboup, M. Fliess (2012) Algebraic parameter estimation of a biased sinusoidal waveform signal from noisy data. *SYSID'2012, 16th IFAC Symp. on System Identification*, Brussels. http://hal.inria.fr/hal-00685067

[3] E. Bernuau, D. Efimov, W. Perruquetti, A. Polyakov (2014) On homogeneity and its application in sliding mode control. *J. of the Franklin Institute*, available online 23 Jan. 2014 http://hal.inria.fr/hal-00942326

All the project's publications are available at
http://www.inria.fr/en/teams/non-a/(section)/publications

Links

http://www.inria.fr/en/teams/non-a

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Pictures

Fig. 1: Increasing constraints on the convergence performance

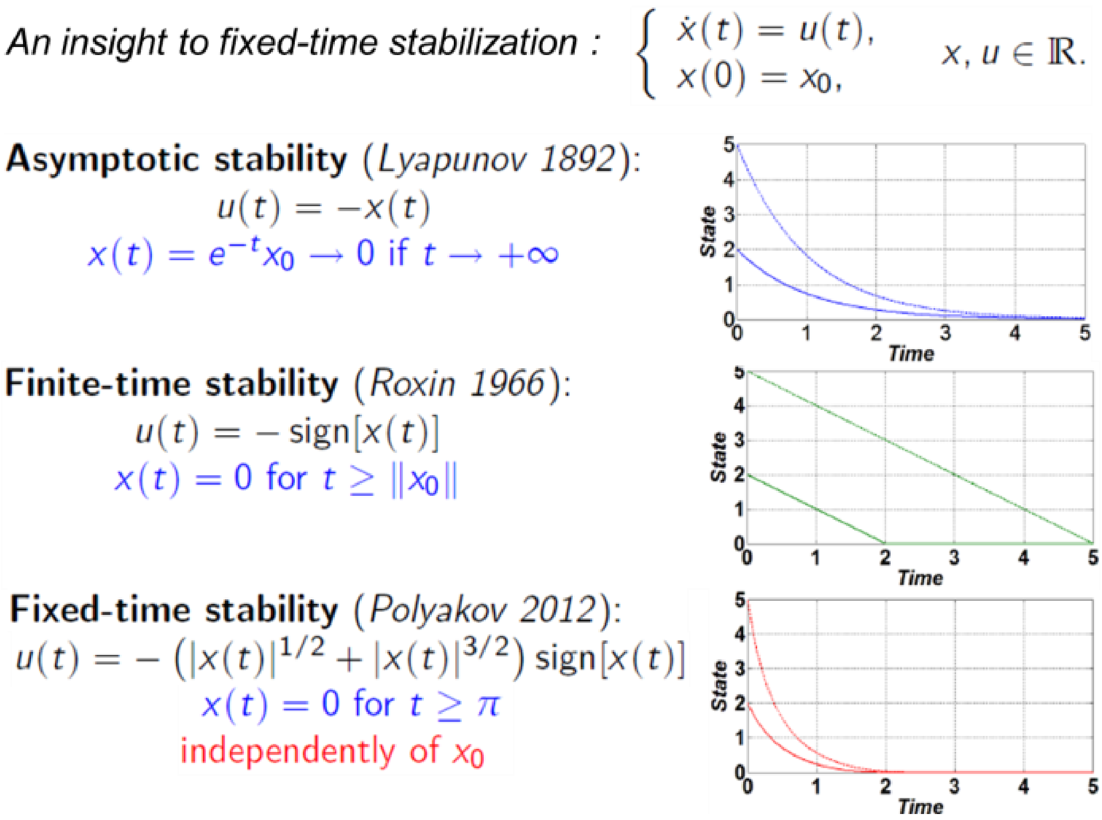
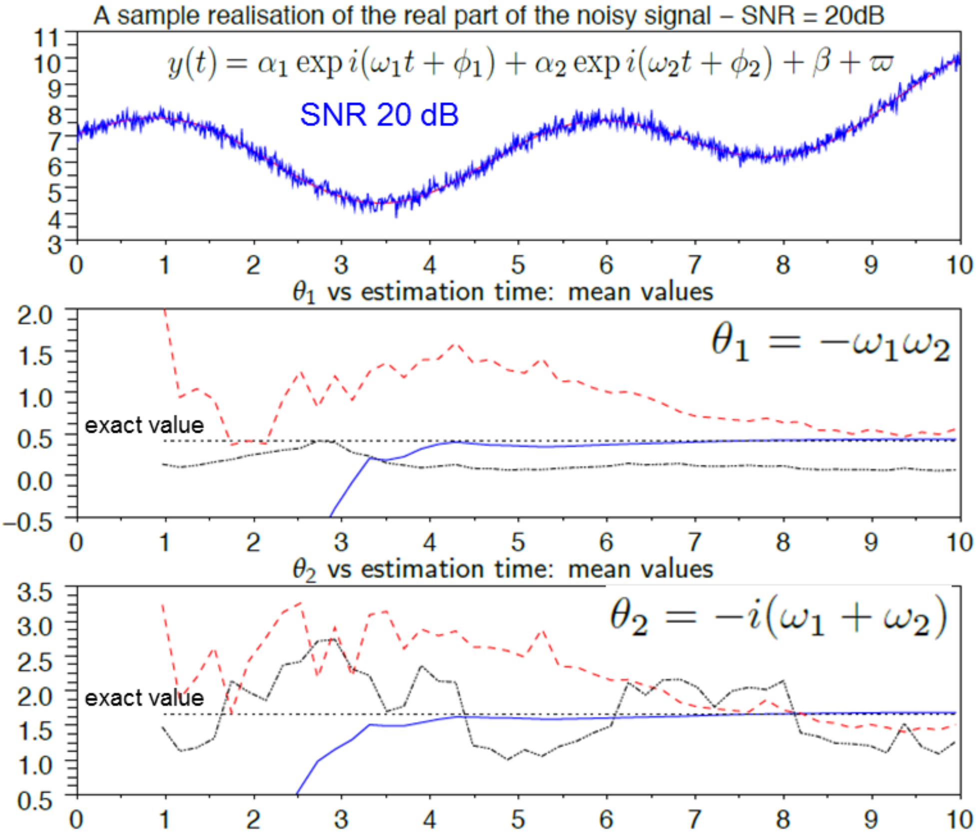


Figure 2: Frequency estimation for noisy signals, taken from [2] – Blue = our algebraic method, Black & Red = Prony-like methods



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